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Electromagnetic Interference from the ILC Beams

LaVonda N. Brown
Office of Science, Science Undergraduate Laboratory Internship Program

Norfolk State University, Norfolk

Stanford Linear Accelerator Center
Menlo Park, California

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Participant: ______________________________
Signature

Research Advisor: ______________________________
Signature

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TABLE OF CONTENTS

ABSTRACT

Electromagnetic Interference from the ILC Beams. LAVONDA BROWN (Norfolk State University, Norfolk, VA 23504) GARY BOWER (Stanford Linear Accelerator, Menlo Park, CA 94025).

Electromagnetic interference is an emerging problem of the future. This investigation analyzed the data collected from airborne radiation waves that caused electronic devices to fail. This investigation was set up at SLAC in End Station A and the data collected from the electromagnetic waves were received from antennas. In order to calibrate the antennas it required a signal generator to transmit the signals to the antenna and a digital oscilloscope to receive the radiation waves from the other antenna. The signal generator that was used was only able to generate signals between 1 and 1.45 GHz; therefore, the calibrations were not able to be completed. Instead, excel was used to create a curve fitting for the attenuation factors that were already factory calibrated. The function from the curve fitting was then used to extend the calibrations on the biconical and yagi antennas. A fast Fourier Transform was then ran in Matlab on the radiation waves received by the oscilloscope; in addition, the attenuation factors were calculated into the program to show the actual amplitudes of these radiation waves. For future research, the antennas will be manually calibrated and the results will be reanalyzed.

1. INTRODUCTION

Electromagnetic interference (EMI) is caused by the airborne radiation of an electric or magnetic field in a circuit [5]. For example, a disturbance on a television set due to lightening is the result of EMI. Since the 1970's high energy physicists worldwide have had a concern with EMI affecting detector electronic devices [5]. After recent research done here at the Stanford Linear Accelerator Center (SLAC) and experiments testing EMI, physicists found that airborne electromagnetic waves were in fact causing of these electronic devices to fail.

Within the past 15 years, the number of radio frequency emission sources that have entered society have increased dramatically [6]. Personal computers, digital pagers, hand-held radios, cellular phones, and wireless input devices have all become more common in the modern environment. Being that these devices are so efficient, electronic mechanisms and wireless technologies will not diminish; in fact greater uses are foreseen [6].

Although these devices provide many benefits, they also create a greater opportunity for increased EMI with devices. It is important that engineers realize the extent of danger these devices can create with complex interactions. Handling this emerging problem should be recognized as a major concern for the medical community since it involves the use of many different electronic devices [6].

We investigated the disruption of electronics by accelerator beam generated EMI. This investigation was being conducted at SLAC in the End Station A (ESA) beam line. The beam generated EMI source is a 2 inch long ceramic gap section of the beam pipe. The beam from the Linac is pulsed at 10 Hz into ESA with bunch charges. In the 1990's when the SLD detector was taking data at the SLC linear collider at SLAC, a problem with the electronics occurred. A work around was created, but the original problem was never understood. In this investigation, we used the same electronic module from the SLD detector that failed.

There were three different antennas used in this investigation: the log periodic (yagi), the biconical, and the diode. All of these pick up signals with different frequencies. The biconical is calibrated for 30-330 MHz, the yagi is calibrated for 650-4000 MHz, and the diode is calibrated for approximately 20 GHz and higher. The diode is the newest antenna and is sensitive to higher frequencies. The antennas measured the electromagnetic waves that the beam produced. The antennas give off a signal when the EMI hits it, and it was important to calibrate these signals in order to calculate its strength [7]. My focus was to calibrate the yagi between 30-330 MHz by using the biconical, and to calibrate the biconical between 650-4000 MHz by using the yagi as a reference. One antenna will be the transmitter of the signal while the other antenna will be the receiver.

It is essential to calibrate the antennas because radiation waves lose amplitude as it transfers from the beam to the oscilloscope [7]. Attenuation factors are used to calculate the actual amplitude of the radiation waves at the instant it leaves the beam. Antenna attenuation factor is not a constant; it is different for different frequencies of signals. This means the recorded signal has to be broken down into its component frequency parts so each frequency can be calibrated [7]. This is one of the reasons we do the Fourier analysis.

I performed a Fourier analysis of the EMI radiation. The EMI signal produced by the beam is picked up by the antennas and recorded on a digital oscilloscope. I then did a

Fourier analysis of the signal by decomposing these waves down into a number of different sine waves with different frequencies and amplitudes. I did this by using Matlab software [4]. Later in the investigation, I wanted to try applying more sophisticated techniques such as wavelet and Frog analysis, but there was not enough time to do so [3].

2. MATERIALS AND METHODS

In this investigation, we measured the amount of EMI that would cause an electronic device to fail. The airborne radiation waves from the EMI were analyzed through the three antennas: the yagi, the biconical, and the diode. We had to turn the beam off multiple times and make many accesses into ESA. During the accesses the antennas were moved around a ceramic gap. Restarting the beam usually took approximately 20 minutes and once it was turned off, one must wait 20 minutes to reenter in order to avoid harmful radiation. One run took approximately 45 minutes so it was extremely important to use time wisely during this investigation.

The beam generated EMI signals were picked up by the antennas and read on the digital oscilloscope. I then analyzed these radiation waves on Matlab by feeding the data into the system in the form of data points. Once I performed a fast Fourier transform on these radiation waves, I then calculated the attenuation factors into the results. By doing so, I found the amplitude and the dominating frequency of the radiation waves that made up these signals.

Once I gathered all my data, I then analyzed it by calibrating the yagi and the biconical antennas. I first gathered the materials which included the Tektronix Digital Phosphor Oscilloscope which has a Windows based interface. In addition, we needed a

Hewlett Packard Synthesized CW Generator which produced a signal for the antennas to calibrate. This signal generator only produces signals between 1 and 20 GHz; therefore, we only can calibrate the biconical from1-4GHz using the yagi as the transmitter (since yagi is already calibrated from 650-4000MHz).

I also needed two 20 foot cables which connected each antenna to either the oscillator or signal generator. A 1.3 foot cable was needed to connect the signal generator directly to the oscillator in order to test the voltage loss. A Fluke 87-True RMS Multimeter was used to insure that the cables were in good shape and had no electrical shorts.

After the materials were gathered, I set up the experiment in ESA as it appears in Figure 1. The yagi was connected to the signal generator and it transmitted signals to the biconical. The biconical was connected to the oscilloscope. I sent different frequencies to the yagi and recorded the data that the biconical produced onto the oscilloscope. After the calibrations were completed, I was then able to analyze the data collected from the fast Fourier Transform.

3. RESULTS

During the calibration of the biconical, I found that the biconical was most sensitive at a 70˚ angle from its original position. Therefore, I gathered all my data with it at this angle. I was only able to calibrate the biconical between 1 and 1.45 GHz because the signal generator was unable to extend any further (Table 1). I was unable to calibrate the yagi anymore than it already is because I could not locate a signal generator in the range of 30-650 MHz. Therefore, I was forced to use the factory calibrations; I extended my calibrations using a curve fitting on the factory calibrations in excel. Figure 2 shows the biconical's extended calibration and Figure 3 shows the yagi's extended calibration.

Figure 4 shows the airborne radiation the oscilloscope measured from the beam pipe. I ran a fast Fourier analysis on the biconical data and figure 5 shows the data. Figure 6 shows the data of the FFT ran on the yagi.

4. DISSCUSSION AND CONCLUSION

I was not able to fully calibrate the biconical or the yagi antenna. Because of this, I was force to use excel to extend the calibrations by performing a curve fitting. These calibrations are not necessarily correct, but for now they will have to suffice. The biconical and yagi's calibrations still need to be extended for future studies.

I successfully ran an FFT on the calibrated radiation waves. I had hoped to see similar calibrated FFT graphs from the yagi and biconical antennas, but that was not the case. In an ideal world, one would suspect that if two antennas are measuring airborne radiation at the same location, that they would show the same electromagnetic waves. For this reason, the investigation still requires more study. Hopefully once the calibrations are done, the FFT's will resemble one another and will prove that the antennas are in fact receiving the same electromagnetic waves.

5. ACKNOWLEDGEMENTS

The research was done the summer of 2007 in End Station A and Building 751 at SLAC. A warm thanks to my mentor Gary Bower who assisted me dramatically throughout the summer. I would also like to thank Nick Sinev for his assistance. A special thanks to the Department of Energy, Office of Science, and SLAC for creating, funding, and organizing this undergraduate program.

6. REFERENCES

[1] A.D. Oliver, A.W. Rudge, K. Milne, and P. Knight, *The Handbook of Antenna Design.* Peregrinus, 1982.

[2] Brigham, E. Oran, *The Fast Fourier Transform and its Applications.* Prentice-Hall, 1988.

[3] Debnath, Lokenath, *Wavelet Transforms and their Applications.* Birkhauser, 2002.

[4] Duane Hanselman and Bruce Littlefield, *Mastering Matlab 7.* Pearson Education, 2005.

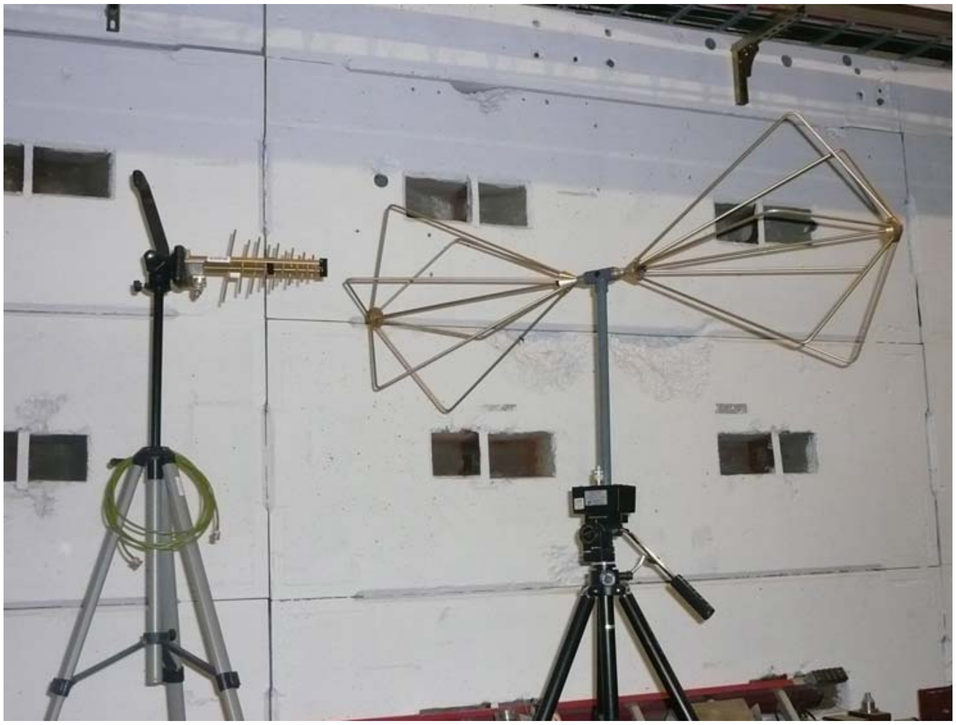
[5] "Electromagnetic Interference." Encarta Encyclopedia. http://encarta.msn.com/dictionary_1861689690/electromagnetic_interference.html.

[6] "Electromagnetic Interference: Causes and Concerns in the Health Care Environment." Institute of Biomedical Engineering Technology. http://ibet.asttbc.org/emi.htm.

[7] Jasik, Henry, *Antenna Engineering Handbook.* McGraw-Hill, 1961.

FIGURES:

(a)



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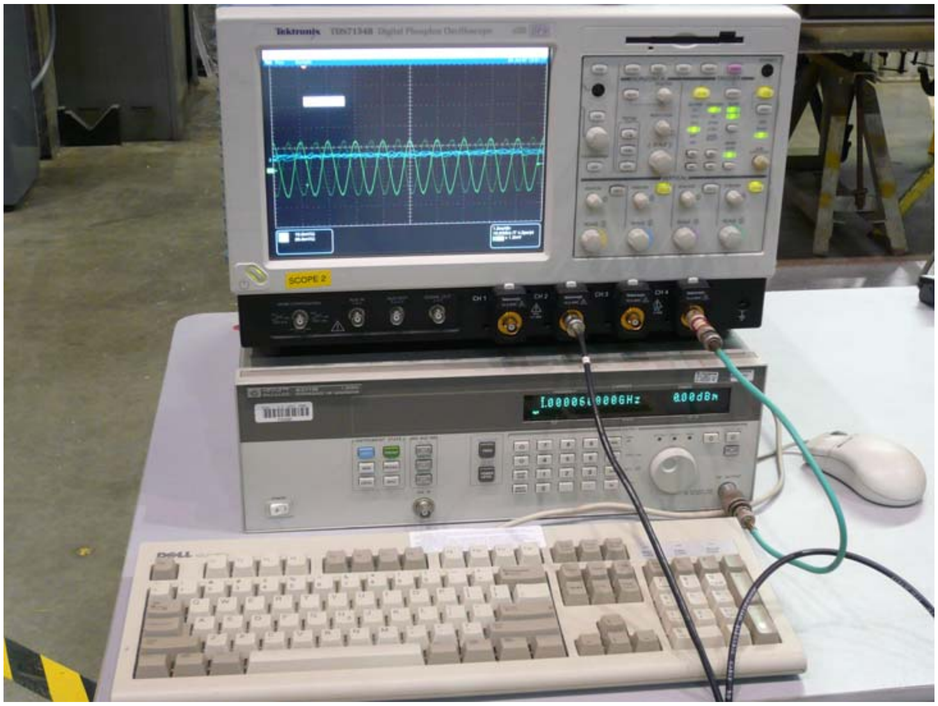
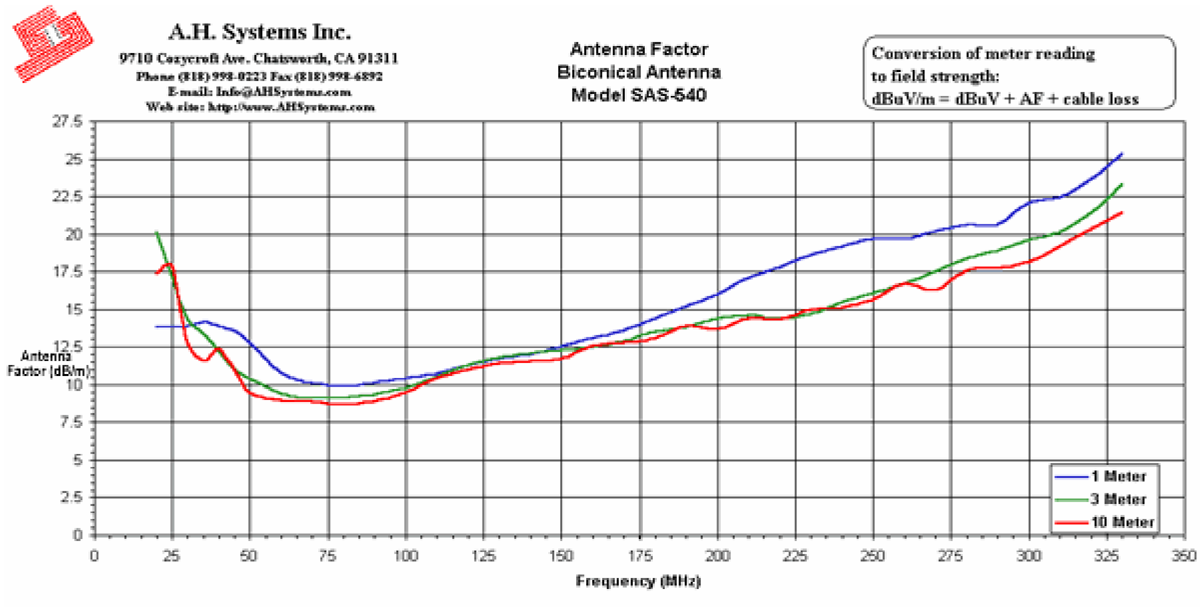


Figure 1: The general setup for the biconical calibration. (a) Left: The yagi. Right: The biconical. (b) The oscilloscope on top of the signal generator.

(a)



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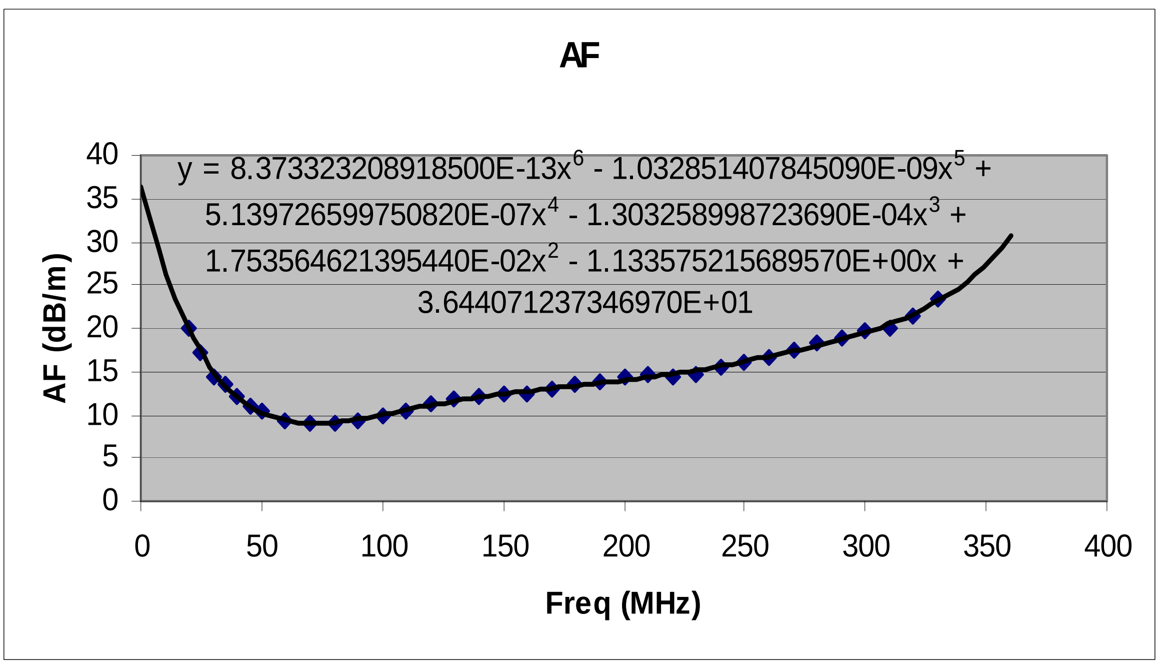
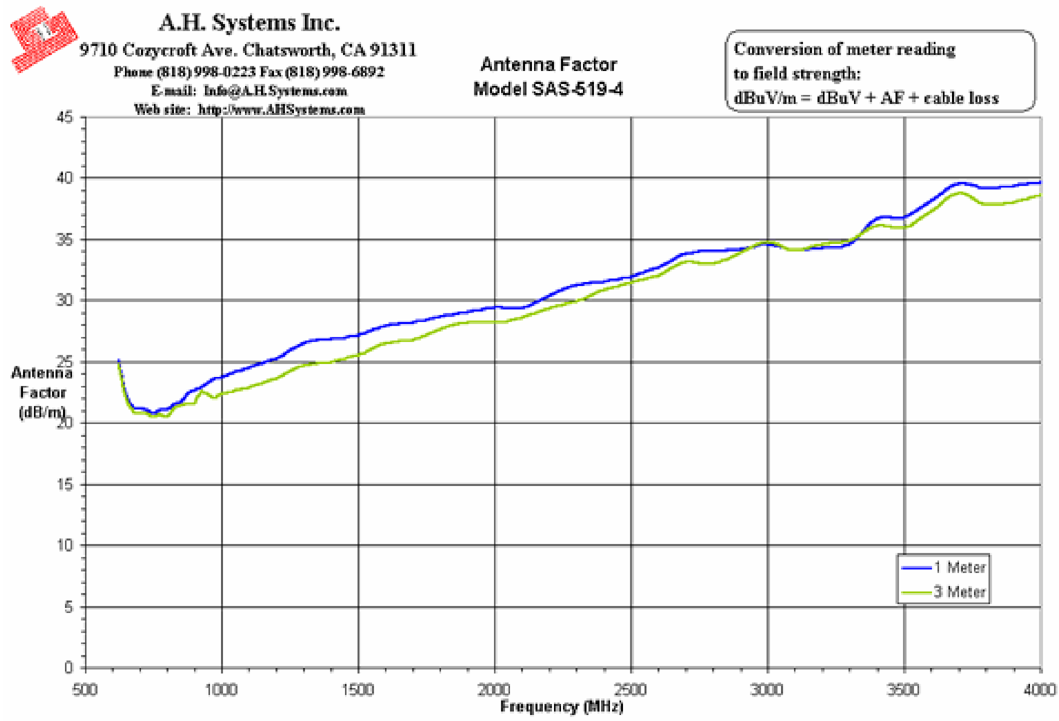


Figure 2: (a) The factory calibrated attenuation factors for the biconical. (b) The curve fitting of the factory calibrations on excel.

(a)



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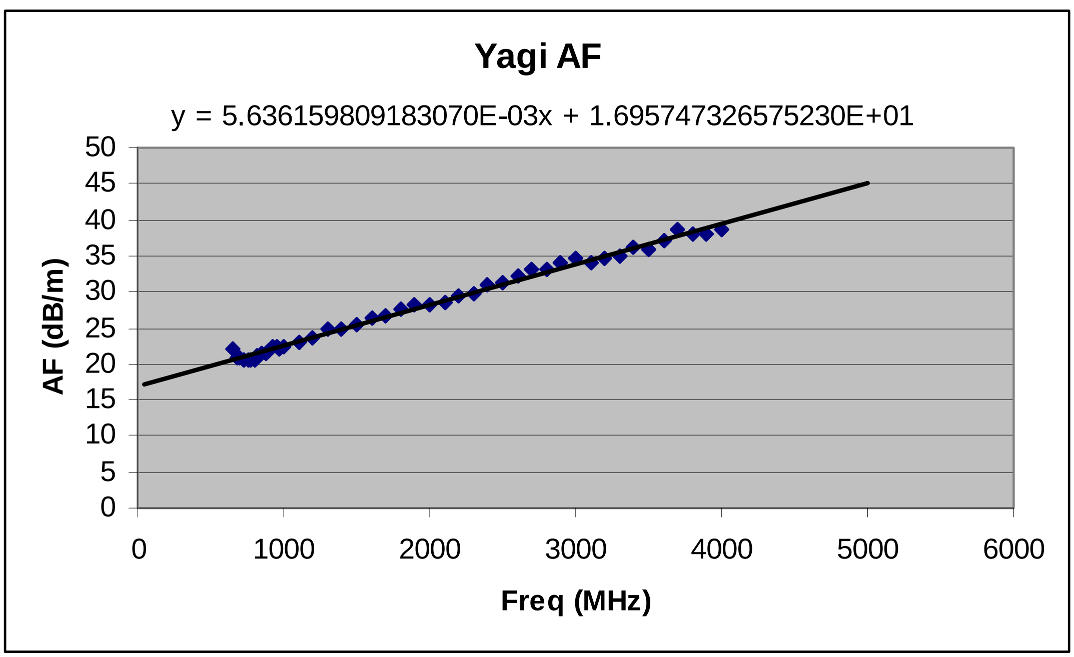
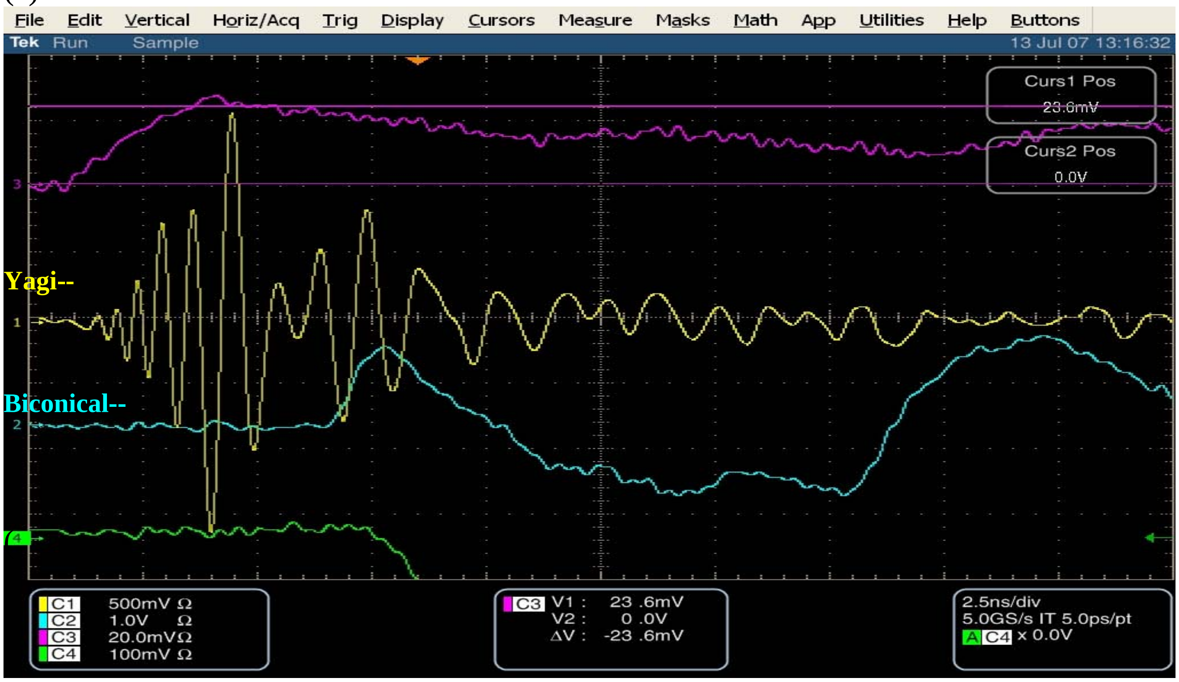


Figure 3: (a) The factory calibrated attenuation factors for the yagi. (b) The curve fitting of the factory calibrations on excel.

(a)



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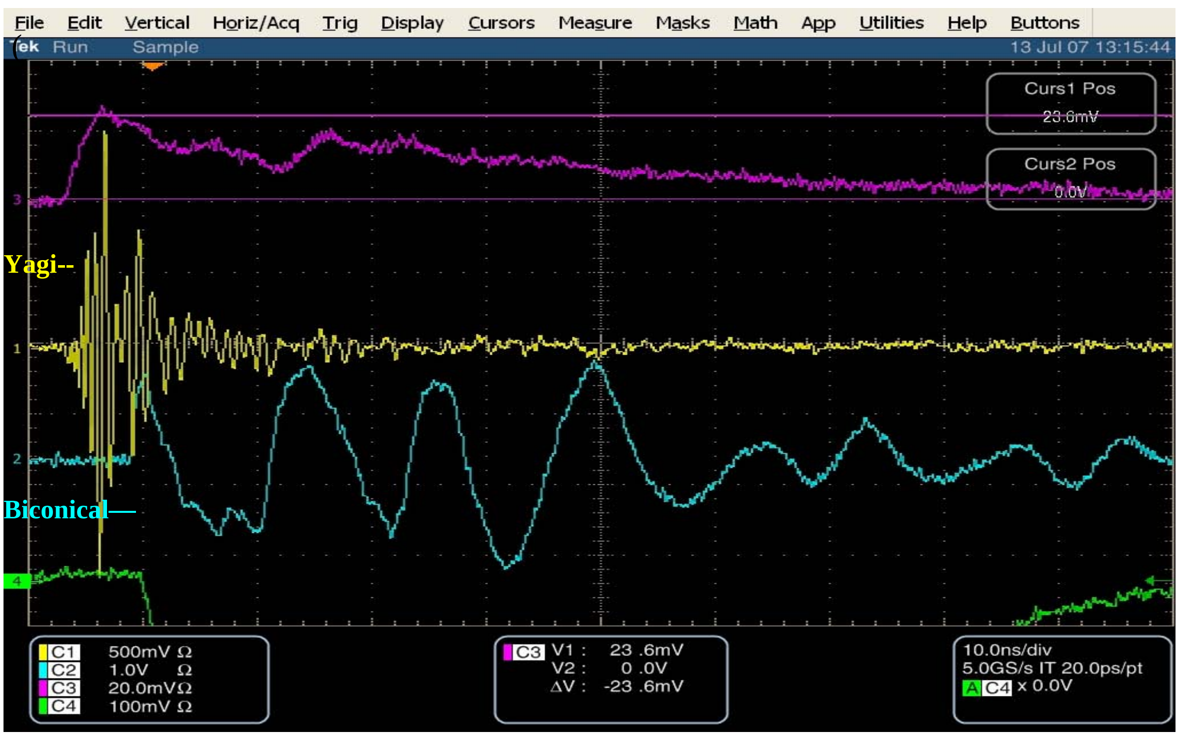

Figure 4: The data collected from the oscilloscope when measuring the radiation waves from the beam. (a) Data collected over a 25 nanosecond period. (b) Data collected over a 100 nanosecond period.

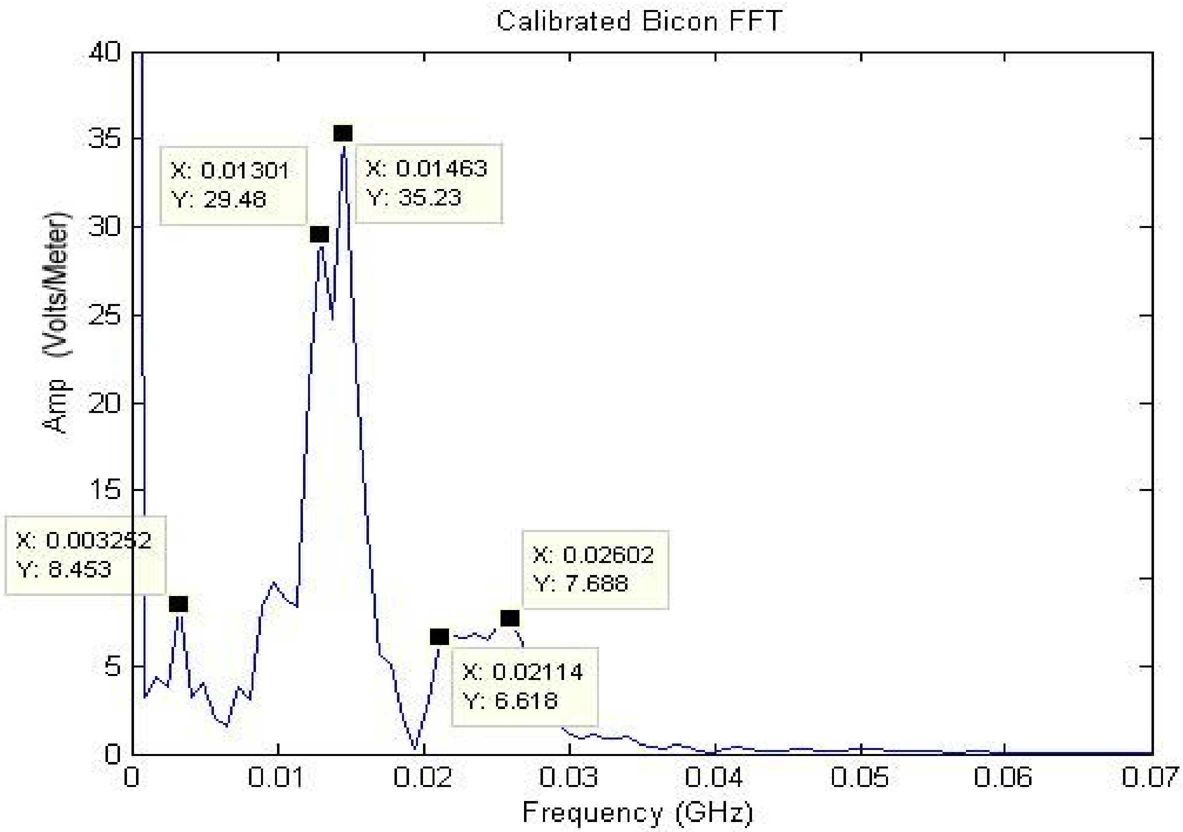

Figure 5: The calibrated FFT of the biconical radiation waves that were projected onto the oscilloscope from Figure 4.

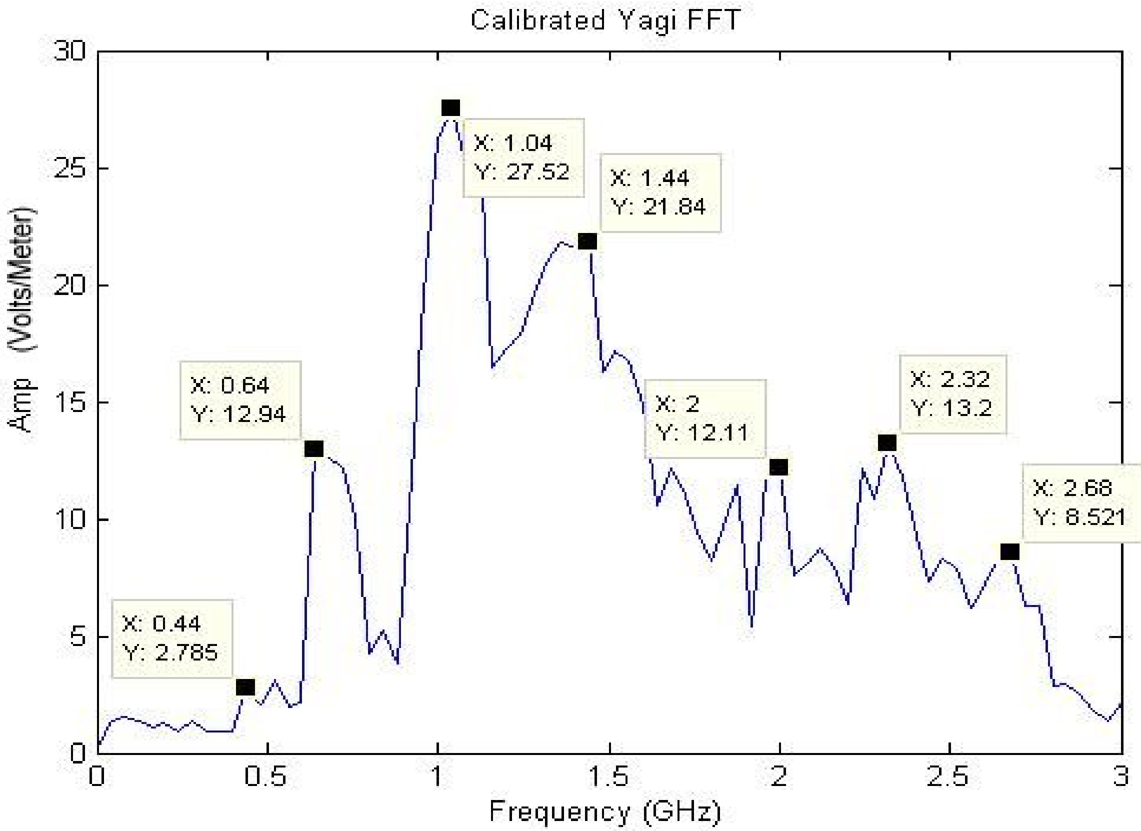

Figure 6: The calibrated FFT of the yagi radiation waves that were projected onto the oscilloscope from Figure 4.

TABLES:

Biconical

Frequency (GHz)	Amplitude (mV)
1	36
1.15	30
1.3	17
1.45	11.5

Table 1: The data collected from the biconical calibrations.